DESIGN CONSIDERATIONS, INSTALLATION AND OPERATION OF THE TWO-STAGE PARALLEL FLOW ABSORPTION CHILLER

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ABSTRACT

This presentation describes the actual design consideration and field operation experience of two-stage parallel flow absorption chillers. The applications include new construction, rehabilitation of old HVAC systems, cogeneration, and industrial process heat recovery.

The high performance (COP = 1.14), and reduced maintenance cost of the two-stage parallel flow absorption chiller provide a notable improvement over the conventional single stage absorption chillers (COP = 0.6). The infamous reputation of the single stage absorption chiller for crystallization, poor mechanical performance, and general unreliability has been completely neutralized by new design concepts incorporated in the two-stage parallel flow absorption chillers. The ease of maintenance and virtual elimination of crystallization has vastly improved chilled water production and mechanical longevity.

The two-stage parallel flow absorption chiller is adaptable to various heat sources including direct fired multi-fuel, steam, exhaust, hot water, thermal fluids, etc. This makes this chiller a worthy consideration as an alternate to electrically driven refrigeration.

The two-stage parallel flow absorption chiller has been operating in the United States since 1979 and presently over 24,000 tons of installed capacity on line. Installations include office buildings, hospitals, computer centers, industrial process water and others.

INTRODUCTION

When fuel was cheap and plentiful prior to 1973, absorption air conditioning represented 40% of the large tonnage market in the United States. As the cost of fuel increased, the operating economy of these relatively inefficient single stage absorption chillers decreased until most of them have now been replaced by other equipment.

Absorption chillers today represent less than 10% of the market in the United States due in Japan, absorption units over 70% of the large tonnage market. The reason for the high market acceptance of absorption chillers in Japan is the one of the highly efficient two-stage, parallel flow absorber.

The two-stage parallel flow chiller discussed herein has been specifically designed to optimize energy efficiency, maintain operational integrity and be compact in size for easy installation, service and repair. No longer are building owners and operators tied to the purchase of electricity for the sole source of air conditioning.

OPERATION

Until recently, it was necessary to have low pressure (15 psig) steam or hot water to produce the state-of-the-art absorption air conditioning. If steam were available from a waste or heat recovery source, then the consideration of absorption air conditioning may still be viable. If, on the other hand, fuel had to be burned in a boiler or heater to produce the heat for the absorption chiller then the cost would be too great. The single stage absorption chiller requires approximately 17,000 to 30,000 Btu's per ton (10t). If a boiler having an efficiency of 80% is used, then the gross fuel input is approximately 25,000 Btu's per ton (10t). This compares to the heat input required for the two-stage parallel flow absorption chillers which is approximately 11,000 Btu's per ton or a gross savings of over 50%. The coefficient of performance (COP) for the two-stage parallel flow chillers varies from 1.21 for the high efficiency steam models, down to 1.1 for the direct fired models.

The lithium bromide reaction in both the older single stage chiller and the new two-stage parallel flow chiller is the same. The lithium bromide is a lower saturated vapor than the refrigerant (water) at a lower temperature than itself. This interaction is called "hygroscopic attraction." The lithium bromide literally absorbs the cool water vapor: therefore the name absorption chiller.

Absorbers today represent less than 10% of the market in the United States but in Japan, absorbers enjoy over 70% of the large tonnage market. The reason for the high market acceptance of absorption chillers in Japan is the one of the highly efficient two-stage, parallel flow absorber.

In the two-stage parallel flow chiller, primary heat is applied to the first stage generator (Fig. Zone 2), to bring the temperature of the diluted lithium bromide solution up to approximately 300 degrees F. at which point the refrigerant vapor (water) is driven off at a temperature of approximately 195 degrees F. The high temperature water vapor is then directed to the second stage of the chiller where it is cooled and condensed (Fig. Zone 3). The latent heat of vaporization from the refrigerant vapor as well as the sensible heat is absorbed in the second stage of the chiller. The hot water vapor given off from the second stage is then condensed by cooling tower water flowing through the condenser tubes (Fig. Zone 4), and mixes with the cooled condensate from the first stage.

The condensed refrigerant now in approximately 105 degrees F. flows from the condenser section of the chiller through an expansion valve and into the evaporator section of the chiller where it is absorbed by the refrigerant pump. The refrigerant pump circulates the chilled refrigerant through specially designed spray nozzles over the evaporator tubes (Fig. Zone 6). The system heat is absorbed from the evaporator tubes and increases

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the heat of the refrigerant causing vaporization.

In the meantime, the concentrated lithium bromide solution from the first and second stage generators has been passed through a heat exchanger (Fig. Zone 1), to lower the temperature and then passed through spray nozzles over the absorption coils (Fig. Zone 6). The cooled lithium bromide absorbs the water vapor coming from the evaporator section, becomes diluted, and is stored in its dilute stage in a reservoir at the bottom of the chiller shell.

A significant contributor to the efficiency of the two-stage parallel flow chiller is the two section counter flow heat exchanger. One section flows solution to and from the first stage generator while a separate yet contiguous section flows solution to and from the second stage generator. The cooled diluted solution from the absorber section of the chiller is passed in a counter direction to the hot concentrated solution coming from the first and second stage generators. This prevents the diluted solution prior to its being pumped into the first and second stage generators. The hot concentrated solution from the generator is cooled by the diluted solution before being directed into the absorber section of the chiller for final cooling and dilution. The counter flow heat exchanger is fabricated by having tubes containing the hot concentrated solution run inside of the tubes carrying the cooler diluted solution in the opposite direction. The maximum efficiency of the counter flow heat exchanger approaches 100% as opposed to a maximum efficiency of the conventional cross or counter flow heat exchanger of only 40%. These shell and tube cross and counter flow heat exchangers are commonly used on the single stage absorbers. Because the absorber section is a high dilution solution into both the first stage and second stage simultaneously, the name PARALLEL FLOW has been used.

Because of the parallel flow and the other significant efficiencies in the chiller shell itself, the two-stage parallel flow chiller is designed to operate significantly apart from the crystallization curve for lithium bromide. This operational design virtually eliminates crystallization problems which have plagued earlier single stage chillers as well as the more recent series flow two-stage absorption chiller.

DESIGN AND INSTALLATION

The two-stage parallel flow absorption chiller has been specifically designed to take advantage of all of the positive attributes of absorption air conditioning while avoiding some of the past problems. The most significant difference in the efficiency of the two-stage parallel flow absorption chiller with COP's ranging up to 1.2, a great deal of economic as well as energy resources can be saved.

The energy or fuel input to the two-stage parallel flow chiller can vary widely. The most prevalent model in the direct fired configuration. This configuration utilizes a multi-fuel, low excess air burner which can utilize most gaseous fuels, but primarily natural gas as an alternate liquid fuel up to and including #2 furnace oil. This means that in cases where emergency air conditioning may be required, the chiller can operate on the same emergency fuel used for the emergency generator. This is certainly a consideration for computer installations, emergency shelters, hospitals, etc. The fuel rate is approximately 11 cubic feet of gas per ton/hour when considering the annual operating efficiency of the system. The specific fuel consumption of the two-stage parallel flow absorption chiller actually improves as load drops from 100%. The average fuel consumption is 0.51 psig to 2000 psig steam from 100% load down to 20% load (5 to 1 turndown).

The next most prominent heat input for the two-stage parallel flow chiller is hot exhaust gas. It is referred to as the cogeneration model. This configuration utilizes hot gas from a gas turbine, internal combustion engine, or process flow to provide the energy to the first stage generator. There are a number of installations currently operating in Southern California where the exhaust from a gas turbine is being taken directly into the two-stage parallel flow chiller. In such cases the overall recoverable heat from the system is approximately 40% greater than in accessible from the use of the old single stage chiller using low pressure steam from a heat recovery boiler.

Steam at approximately 15 psig can also be used in these two-stage parallel flow chillers. The standard steam chiller has a heat input of 10,500 psig per Ton-hour (115 psig). There is a high efficiency steam model available that has a heat rate of 9.9 psig per Ton-hour (COP = 1.21).

Water, thermal fluids, and other heat sources can also be considered as prime energy input for specifically designed chillers.

A significant design feature of the two-stage parallel flow chiller is that it can also be a heater. The hot refractory design of the first stage generator can be passed into a shell and tube condenser rather than having it all go into the absorber shell. If system water is passed through the condenser, heat can be absorbed to condense refrigerant which will then flow directly back into the first stage generator. It is possible to generate hot water for space heating and/or domestic hot water at temperatures from 140°F to as high as 175°F. The water can also be made available simultaneously with the production of chilled water for air conditioning. When the chiller/heater is producing a minimum of 35% of its refrigeration capacity, it can simultaneously produce as much as 45% of its heating capacity. As cooling requirements increase, the available heating production decreases proportionately. When no refrigeration is needed, the complete fuel input of the chiller/heater can be extracted as hot water at an efficiency of 90%. This compares quite favorably to any commercially available boiler or hot water generator.

The conventional single stage and two-stage series flow absorption chillers are sized for condenser water inlets at 85 degrees F. If, indeed, the condenser water entering temperature increases, then either the capacity of the chiller must be decreased or additional mechanical cooling could ensue. The two-stage parallel flow chiller on the other hand, is designed to operate on condenser water running as
high at 92 degrees F., entering. Although the design point is at 85 degrees F., condenser water at 92 degrees F. will not require derating of the machine. It will necessitate a somewhat higher specific fuel input, but the full capacity of the machine is still available at a time when it is needed the most. Also, to effect greater savings, the two-stage parallel flow chiller can be operated with condenser water temperatures ranging down to 69 degrees F. If you consider that every one degree reduction in condenser water temperature below the rated 85 degrees F. results in a 1% efficiency increase, then substantial savings can be gained by using a condenser water reset program to optimize efficiency.

The two-stage parallel flow chiller/heater lends itself to the incorporation of energy management control strategies. As mentioned above, the condenser water temperature can be reset from the design of 85 degrees F. up as high as 95 degrees F. or down as low as 69 degrees F. As the cooler condenser water is available, its use will enhance the energy efficiency of the chiller. The chilled water can also be reset from the design point of 44 degrees F. up to approximately 55 degrees F. without causing any damage whatsoever to the operation of the chiller/heater. The efficiencies will increase at a rate of approximately 1 to 1.5% per degree increase in chilled water temperature output. Whether using direct fired, steam, waste gas, etc., the control mechanism can be modulated to provide infinite positioning for optimum energy efficiency.

Although the standard condenser water flow rate is predicated on a 10 degree Delta T temperature differential (85 degrees F. in - 95 degrees F. out), an 85 degrees F. to 100 degrees F. condenser is available. The use of this expanded condenser rate reduces pumping horsepower as well as piping size, usually fitting the same footprint of the standard condenser. This reduces pumping horsepower as well as piping size, usually fitting the same footprint of the standard condenser. The two-stage parallel flow chiller/heater can also be reset from the design point of 44 degrees F. up to approximately 55 degrees F. without causing any damage whatsoever to the operation of the chiller/heater. The efficiencies will increase at a rate of approximately 1 to 1.5% per degree increase in chilled water temperature output. Whether using direct fired, steam, waste gas, etc., the control mechanism can be modulated to provide infinite positioning for optimum energy efficiency.

The viability of absorption cooling was thought to be dead in this oil and gas rich region. Perhaps the most significant installation of these units is for the Pacific Telephone Company in San Diego, California. Pacific Telephone installed a cogeneration system for their computer center, which included three 2100 kW steam turbines and two 1800 KW steam turbines which operated from exhaust heat boilers. They also installed three 450 ton two-stage parallel flow chillers to operate from the turbine exhaust and three direct fired steam absorption chillers. The entire system has been on-line since December of 1982 and has functioned to the complete satisfaction of the Telephone Company and its design engineers. Plans are now in design to use this installation as a guide for other computer power centers.

CONCLUSION

The viability of absorption cooling was thought to be dead in this oil and gas rich region of the Southwest except for those few areas where waste steam was available from some industrial process. However, with the availability of the two-stage parallel flow chiller/heater either directly fired withBagard gas or using steam from process boilers, the economics of air conditioning again favor absorption. There is Indeed an
alternative to the electric air conditioning cost spiral. With a little use of imagination and the proper consideration of the second law of thermodynamics, a designer can reap handsome dividends in the conservation of both economic as well as energy resources by using the two-stage parallel flow chiller/heater.